VOLUME 79 SEPARATE No. 208

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

JULY, 1953

THE KEY WEST AQUEDUCT

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Presented at
Miami Beach Convention
June 16-19, 1953

SANITARY ENGINEERING DIVISION

{Discussion open until November 1, 1953}

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Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

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This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

THE KEY WEST AQUEDUCT

by P. Corradi and Burr Lenhart

On February 1, 1823, Commodore David Porter, United States Navy, was ordered by the Secretary of the Navy to "establish at Thompson's Island, usually called Key West, a naval depot, and land the ordnance and marines to protect the stores and provisions." Since that date, the history and the development of Key West and the other Florida Keys has been inextricably intertwined with the development of naval activities there.

It is not surprising, therefore, to find that the Navy has constructed, and operates today, the water supply system which furnishes the Florida Keys with their economic life blood.

Early Water Supply

Prior to 1942, the principal source of water supply for the inhabitants of Key West and the Keys lay in the direct collection of rainfall. In some cases, this rainfall collected into natural pools, which in due time became brackish; in others, the water was collected from roof gutters and catchment areas and stored in cisterns. The use of brackish water and salt water was widely practiced wherever such use was practicable. But the main potable and industrial water needs had to be met by the use of rain water from cisterns and other forms of storage, augmented by water barged in from other available sources and water produced by distillation of brackish or sea water.

Following the inauguration, between 1908 and 1912, of passenger and freight traffic by the Florida East Coast Railway Co. on its overseas extension from the mainland to Key West, water was imported by tank cars to Key West and other points on the Keys. But while this arrangement made water from the mainland more available to Key West users, the price of such water delivered was very high, - higher, indeed, than the average Key West citizen could be expected to pay. Furthermore, the lack of storage made the water supply a tenuous one.

During the first World War, the expansion of the Naval Station at Key West made the construction of water supply facilities necessary and there was therefore authorized the installation of eight (8) wooden tanks, two (2) concrete cisterns, and two (2) gravity tanks having a total capacity for the storage of rain water of 285,000 gallons.

Following World War I, the industrial development of Key West was brought to a virtual standstill. By 1932 and with the closing of the Naval Station that year, the economy of the area reached a very low ebb, with a large percentage of the total population subsisting on relief payments made by the government.

The hurricane and tidal wave of September, 1935, which washed out large sections of the railroad, resulting in its abandonment in 1936, brought an end to the importation and distribution of water by rail. But during the railroad's brief existence, a general knowledge of the tropical splendors of the entire Florida Keys area was gained by the public. The area beckoned to fishing and boating enthusiasts and to vacationing tourists generally. Indeed, by this time

the economy of the Keys had gradually changed from cigar making and commercial fishing to the tourist trade.

Florida Keys Aqueduct Commission

Private enterprise, ever on the alert to exploit the natural advantages offered by the Keys area, was early to realize the prime importance of water supply to the Keys. If the Keys were to be developed as a vacation land, the provision of a usable water supply was the first requisite. The citizenry of the State of Florida, generally, were anxious to develop this tremendous area in the southern part of their state in order to further promote the tourist trade. The subject grew in importance until, finally, the State Legislature enacted House Bill No. 1683, Chapter 18530 of the Acts of Florida 1937, which was approved by the Governor June 11, 1937. This Bill created the Florida Keys Aqueduct Commission. Commissioners were first appointed in 1938. The Commission has been described as:

> "an agency of the State of Florida and a body corporate and politic authorized to construct, maintain and operate an aqueduct and water distribution system for supplying water in the Florida Keys area, embracing the Florida Keys and extending from the mainland to the City of Key West."

The Commission sought to work out a method of financing such an aqueduct with the help of the Works Project Administration, the Public Works Administration, and other Federal agencies, but without success, and the dream of a dependable water supply for the Keys apparently ended.

Water Supply Need Becomes Urgent

History shortly changed the water supply situation, however. The Naval Station at Key West was reopened on November 1, 1939. An expansion program was undertaken so as to equip the station to perform its mission of training our anti-submarine warfare units. Hitler's evergrowing undersea fleet made it imperative that our Navy be provided such facilities immediately.

At the outset of the construction program the Navy and the civilian population at Key West found the rain water supply to be dwindling, both in storage and in actual precipitation. For years the Navy had augmented its own stored supply by the use of evaporators located at the main station and at the Naval Air Station. It also resorted to the use of Navy water barges to import water when necessary. There was some interchange of water between the Navy and civilian users when circumstances permitted. The records show, for instance, that in 1941 the Navy purchased from the Casa Marina Hotel some 250,000 gallons of water at $3.00 per thousand gallons. A high rate, it would seem to be, but probably cheap under the circumstances.

About this time, the international situation worsened and accentuated the need for Navy action toward the procurement of an adequate water supply to meet its needs at Key West. The total evaporator capacity even under full operation, was only 82,000 gallons per day. Water storage capacity consisted of 5 million gallons at the Naval Station and 2 million gallons at the Naval Air Station. The needs for distilled water for ships and other uses were running about 75,000 gallons per day. Thus the storage capacity, even though available, could never be maintained anywhere near full. A breakdown of evaporator equipment at any time would have created a real emergency. Difficulty

was also encountered in obtaining suitable barging equipment for the importation of potable water to meet the general deficit in supply for all uses.

A decision was made by the Navy to immediately proceed with the construction of an aqueduct to transport water from the mainland to meet its Key West requirements. An appropriation was requested from the Congress for a water supply line for the Naval Station, Key West. The cost was estimated to be $2,000,000 for a 12-inch diameter aqueduct to serve Navy needs. The Congress appropriated the money in that amount, but added a provision that the water line might be constructed in conjunction with an agency of the State of Florida. The addition of this latter provision resulted from the efforts of the Florida legislators in support of the aims of the Florida Keys Aqueduct Commission.

On July 15, 1940 the Commission, by letter, suggested that it was better able to handle the public utility angle of water distribution than the Navy Department. By resolution, the Commission on September 27, 1940 formally petitioned the Navy Department to allow it to participate (in the cost of project) in an amount of $1,000,000 to permit an

> "Optimum dimension of the water conduit ---- to supply ---- all governmental agencies, and the needs and requirements of the civilian population of the Florida Keys district."

Meanwhile the engineering firm of Parsons, Klapp, Brinckerhoff and Douglas of New York was employed by the Navy to design the water line. In December, 1940, the engineers submitted an estimate of $2,034,000, based on a 12-inch diameter line to serve Navy needs alone. Their preliminary plans were approved.

Upon receipt of the Commission's petition for participation, and the acceptance of same by the Secretary of the Navy, action was taken to negotiate the terms of an agreement between the two parties.

Agreement Between Navy and Florida Keys Aqueduct Commission

Under date of March 18, 1941, the Navy Department entered into a formal agreement with the Florida Keys Aqueduct Commission, whereby the Navy would construct, maintain, and operate a water supply system consisting of wells, pumping plant, and an aqueduct with a nominal capacity of 3,000,000 gallons per day. At the time the agreement was executed, the cost of this water supply system was estimated at $3,000,000. The agreement provided $2,000,000 to be furnished by the Navy and $1,000,000 by the Commission. (After bids were taken, the overall cost of the project was re-estimated at $3,375,000, of which the Commission agreed to pay $1,125,000.)

Some of the salient provisions of the agreement are outlined as follows:

(a) Construction and Operation: By the U. S. Navy.
(b) Division of Water Supply: Navy, two-thirds; Commission, one-third.
(c) Cost of Operation and Maintenance: To be shared on the basis of the proportional amount of water delivered to each.
(d) Distribution Facilities: Construction and operation of all facilities necessary for delivery of water from the aqueduct to the Commission's distribution system, including any necessary booster stations, to be provided by the Commission.
(e) Title: Title to the Aqueduct to be vested in the Government.
(f) Repairs and Replacements: Commission to pay one-third of the cost of all major repairs or replacements.

Upon receiving indications that this agreement would be consummated, the Navy had instructed its engineers to proceed on the basis of an aqueduct and plant capable of producing 3,000,000 gallons per day, or an 18-inch diameter aqueduct instead of a 12-inch diameter one.

Original Design of Aqueduct

Pursuant to instructions from the Navy, the engineers designed the water system to comply with the requirements of the agreement.

The design features of the water system, as it was originally constructed by the Navy are outlined as follows:

(a) A Well Field and Pumping Plant at Florida City, Florida comprising:
   1. Three (3) shallow wells.
   2. Two diesel engine driven pumps with a design capacity of 2.2 million gallons per day with one unit operating and a capacity of 3 million gallons per day with the two pumps operating in series.

(b) An aqueduct, 128-miles long, 18-inches diameter, with 1/4-inch thick steel walls, coated inside and out with bituminous enamel and wrapped with felt. The pipe line was coupled with Dresser sleeve-type couplings, and at bends and underwater crossings the couplings were equipped with harness sets to prevent the pipe from pulling apart. All couplings were equipped with metal-tipped gaskets intended to make the pipe a continuous electrical conductor in order that electrolytic protection could later be provided. The pipe line included thirteen underwater crossings between the Keys, of which four are at navigable channels. The design was based on using cast-iron pipe with metropolitan joints at the underwater crossings. (Actually, due to slow delivery of cast-iron pipe, steel pipe was used at all of the crossings, except Moser Channel and Channel #5.) In general, the aqueduct was laid out along the right-of-way of the Overseas Highway, parts of which were under construction at the time. Approximately twenty (20) miles of the line is laid on the Highway bridges.

Construction Procedures

Materials for the aqueduct were purchased by the Government under five (5) lump sum contracts. The labor involved in installation of the pipe-line, etc., was accomplished under four (4) separate lump sum contracts running concurrently or as best suited to the construction program needs. By this means, the delivery of critical materials to the site was expedited, construction was more rapidly accomplished and the actual date of delivery of water through the aqueduct was greatly advanced. Some advantage was also derived from the fact that orders for materials could be placed sooner, allowing their purchase on a market which had not yet started to rise as a result of World War II.

The pipe was procured under Schedule 5441, early in 1941. This Schedule covered Pipe; Steel, Cast Iron, Cement-Asbestos, and Wrought Iron. The bids on steel pipe were found to be lower than those on other types of pipe. However, none of the steel companies bid on the full requirements, and it was necessary to accept the bids of two steel pipe companies whose bids were in conformance with the Schedule. Award was made to the American Rolling Mills Co. and to the Youngstown Sheet and Tube Co. who supplied approximately 180,000 lin.ft. and 433,000 lin.ft. respectively to the Government, f.o.b.

Homestead, Florida. Under these conditions, Government freight rates applying, the respective unit prices were $2.0953 and $2.0754 per lin.ft. The pipe was furnished in double random lengths, averaging 38 feet or over.

Coupling and touch-up compound was purchased from the Barret Co. Pumps were furnished by Fairbanks-Morse Co.

Once the materials had been purchased, construction contracts were awarded. The Standard Asbestos Manufacturing and Insulating Co. of Kansas City contracted to line, coat and wrap the pipe. Another contract with the same firm provided for the unloading and stockpiling of the pipe at Homestead, Florida. Coal-tar enamel lining was provided for the pipe, while the exterior protection consisted of a priming coat applied over a cleaned surface, followed by a coal-tar enamel coat and a single wrapping of tar-saturated rag felt weighing approximately 24 lbs. per hundred square feet. Retouching and coupler compounds used were of coal-tar base and applied at the site.

The Williams Bros. Corp. of Tulsa, Oklahoma submitted the low bid for the work involved in the laying of the pipe, and were awarded the contract. The laying contractor was notified to proceed with the work on December 8, 1941. In the course of the work, this contractor also constructed the Pumping Station at Florida City (Fig. 2) and performed other miscellaneous parts of the installation as changes under the basic contract.

The aqueduct was placed in service in November of 1942. Service has been maintained from that time on.

Construction and First Operational Difficulties

A brief examination of Fig. 1 will acquaint the reader with the general extent and nature of the work involved in the aqueduct project. On the land sections of the route, the pipe was installed underground, as a rule; while at points between the Keys, it had to be supported from existing bridge structures, or, where no bridges existed, in trenches at the bottom of the various water passages.

It must be realized that all during the construction period, the work proceeded under conditions of the greatest urgency. Work in connection with the construction of the Pumping Plant at Florida City (Fig. 2) and that involved in the laying of the pipe at various points along the route proceeded simultaneously. All possible short-cuts to completion were employed.

Some of the general types of equipment used by the laying contractor are illustrated in Figs. 3, 4, and 5. The conditions under which parts of the work proceeded are shown also by these illustrations.

The urgency under which the work was accomplished increased with time. The Navy was primarily concerned over the rapidly growing need for more and more water at Key West. As the Navy's construction program at Key West took shape, more and more workers were imported by contractors; the limited water supply was stretched to its limit; but still the progress of the program was threatened. An adequate water supply became of increasing importance, resulting in extraordinary pressure being placed upon the aqueduct contractors to complete the installation sufficiently to deliver water to Key West at the earliest possible date.

Anchorage Troubles

Because the pipe line had to be placed into operation before all phases of the construction had been completed, it was to be expected that various weak

points should develop during the testing period. Operating at normal pressures on the line, water was being delivered at Key West to meet its minimum needs. This condition obtained even before some of the anchors at bends in the line had been placed. When the line was later subjected to a test pressure of 450 lbs. per sq.in., the line blew out at these bends as might have been expected. Suitable anchors were installed as soon as this could be done, after which troubles from this source no longer occurred.

Corrosion Difficulties

Even before the replacement of the cast-iron pipe underwater crossings had been completed, numerous large leaks developed in the underwater crossings at Tea Table Channel (See Fig. 1). These leaks were found to be due to corrosion at the exterior surface of the pipe structure, and at the couplings, bolts, etc., wherever the coal-tar enamel and wrapping had been bruised or broken off. The contractor was authorized to remove this piping and to replace it with welded steel pipe supported on timber pile bents above the water. Replacement work was not accomplished without difficulties. First of all, service had to be maintained. This was accomplished by providing a double by-pass on the east side of the Tea Table Channel Bridge, then tying into the main aqueduct on each side of the channel after having blank flanged the two ends. (See Fig. 6, which shows one by-pass mounted on the water side and the other on the traffic side of the bridge rail.)

Difficulties were encountered in undertaking the replacement work itself due to the rapid current through the channel. The wash at the barge shown in Fig. 7 indicates the swiftness of this current during certain working hours of the day.

After the double by-pass had been installed at Tea Table Key Bridge, the removal of the pipe was started in the channel on January 14, 1944.

The backfill which had originally been placed in the trench over the pipe had been washed out by the very swift current. The contractor therefore had very difficulty raising the pipe. Starting at the middle of the channel, the harness set bolts were cut and the pipe sections pulled out of the dresser couplings and set on a barge without causing any appreciable damage to the enamel. Three pipe sections were removed on Friday, January 14th and one section on the following Sunday. These four sections were examined very carefully and the corroded areas photographed.

Original Damage to the Coating

Damage which had apparently been done at the time of laying may be classified as follows:

(a) Cuts from cables.
(b) Cuts from dragline or from clamshell.
(c) Bruises - probably from rock in backfill or jagged rocks in the side of the trench.
(d) Bruises from laying pipe on rock in bottom of trench.

Damage to Pipe Structure

Wherever the enamel had been knocked off or damaged, corrosion had occurred. There was an average of approximately 20 corroded spots per length of pipe, of which about one-quarter were eaten entirely through the

1/4-inch steel plate. Figures 8 to 13, inclusive, show the nature of corrosion damage at this underwater crossing.

The largest single hole was about 1-1/2-inches long x 3/8-inch wide. (Fig. 11) It is to be noted that at many places where the enamel was still in place, but had apparently been disbonded by bumping, corrosion under the enamel had taken place. This was probably due to fine cracks in the enamel, resulting from the bumping, which permitted moisture to reach the metal.

No corrosion of the pipe was evident anywhere except at places where there was evidence of structural damage to the enamel. No corrosion appeared to have originated on the interior surfaces.

Conditions of Couplings and Harness Sets

There were signs of corrosion on all bolts and couplings at those places where it had been difficult to apply the enamel. The most serious corrosion observed was on the bolts where the threaded ends passed through the follower rings. (See Fig. 8) The tie bolts on the harness sets were similarly affected where the bolts passed through the lugs. (Fig. 9) The reduction in diameter was about 1/16-inch for typical coupling bolts and nearer 1/8-inch for harness set tie bolts.

Miscellaneous Comments on the Tea Table Channel Findings

The pipe trench had been backfilled with sand, but there was actually no backfill over the pipe when examined by the Navy diver at the time the leaks were discovered. A large percentage of the corroded spots occurred on the upper half of the pipe. The swift current in the channel flowing across the pipe line was undoubtedly responsible for washing out the sand backfill but there was no sign of any scouring action. The large percentage of corroded spots on the upper half of the pipe, pointed to the possibility that the backfill may have contained some rock. A large telephone cable was laid parallel to the underwater crossing and about 15 feet away from the pipe. The corrosion probably had been accelerated by electrolysis due to stray currents from this cable. It is of particular significance that the pipe line had been in place only 18 months.

Cathodic Protection

The experience at Tea Table Channel, and reports of additional leaks at other places, alerted the Navy to the possible danger of corrosion causing a complete failure of the aqueduct. Close examination of the damage led to the conclusion that the corrosion was resulting from electrolysis. Without further delay, the Navy arranged for a study of the aqueduct to be made by Mr. Starr Thayer, Houston, Texas, a recognized authority on the subject of electrolysis and cathodic protection. Mr. Thayer indicated in his report that the pipe line could be saved if cathodic protection were to be installed. His tests showed, however, that the metal-tipped gaskets, which had been supplied with the pipe couplings, failed to make the pipe a continuous electric conductor as had been claimed by the manufacturer. Mr. Thayer, therefore, recommended that copper bonds be installed across all of the couplings on the land sections. The estimated cost of bonding the entire line was $150,000. Before doing this, however, the Navy decided to first try out cathodic protection on a short section of the line. This was done by applying cathodic protection to a section of the line extending from Lignum Vitae Channel northerly

approximately 19 miles. Cathodic protection was also applied at the troublesome crossing at Moser Channel and Channel No. 5, where the pipe could not be raised above the water on account of the navigable channels at these locations. The remarkable reductions in leaks which resulted from the trial application of cathodic protection to these sections of the pipe line entirely justified the expenditures made in applying cathodic protection to these sections and led to the adoption of electrolytic protection to the balance of the aqueduct. Also, on the basis of what was learned in these studies, the Navy relaid on pile bents above the water surface all the pipe at the water crossing and for the 4-1/2-mile stretch north of Jewfish Channel (Fig. 14), where the pipe had originally been laid in mangrove muck and had developed scores of leaks due to the unusually severe corrosion conditions which existed in that area.

Water Treatment Provided

In April 1944, as a result of growing complaints from naval vessels being served at Key West with water from the aqueduct, it was decided that a softening plant would have to be provided. The civilian consumers served by the Commission were satisfied with the raw water as pumped from Florida City, but officials of the Naval Operating Base insisted upon appropriate treatment to condition the water to meet the special needs of naval vessels at the Base. It was decided to install water softening equipment at Florida City with the Navy financing the cost of installation and the Commission sharing only in the cost of its operation and maintenance.

This softening plant, of a capacity of 2.4 million gallons per day, was completed at the Florida City source of supply in 1945 and had been in operation since that time. (Fig. 2) The equipment consisted of three spiractors, each of .8 mgd capacity, manufactured by the Permutit Company, three rapid sand filters of similar capacity based on a filter rate of 2 gallons per square ft. per minute, and a clear well of about 220,000 gallons capacity. As the consumption of aqueduct water increased later, it became necessary to mix treated and raw water to meet the demand. Scarcely had means been found to finance this work and get it under way, when increasing civilian demands made necessary further action to improve and increase the water supply.

The Marathon Booster Pumping Station

In September 1944, the Secretary of the Navy, acting upon the recommendations of the Commandant, Naval Operating Base, Key West; and the President's Committee for Congested Areas; and with the support of the United States Public Health Service, sought means of increasing the capacity of the aqueduct to meet evergrowing civilian needs. Since the pumping equipment installed at Florida City under the original Construction project did not deliver the full quantity of water for which the pipe line was designed, the Navy immediately took action to correct this shortcoming. The Florida City pumps, as originally installed, delivered from 2.2 to 2.4 million gallons per day, whereas the desired capacity of the aqueduct system was 3 million gallons per day.

Investigations determined the necessity and practicability of establishing at Marathon, Florida, a Booster Pumping Station, including 100,000 gallons reservoir capacity to permit smoothing out the pumping operation. Electrical power not being available at the time, it was decided to use at that location

one of the diesel-driven units, originally installed at Florida City. One of the two units at Florida City was accordingly moved to Marathon and was in turn replaced by an electric motor-driven unit in the main pumping station at Florida City. This arrangement worked well, and as a result the capacity of the aqueduct was raised to 3.2 million gallons per day. With the new setup, it was actually possible to pump as much as 3.9 million gallons per day through the line for short periods. This was not ordinarily done, however, because it was felt that trouble might develop if the necessary line pressures were held over an extended period.

Additional Well at Florida City Source

The construction of the Booster Pump Station at Marathon should have solved the supply problem since the aqueduct could now deliver more than its originally designed capacity. However, the increasing development along the Keys and a low rainfall period of several years required additional improvements to the system to be made in 1944.

Low rainfall in southern Florida during 1943 and 1944 had caused the ground water level to gradually recede. Because of this condition, the flow from the three existing artesian wells at Florida City was not sufficient to supply the steadily increasing requirements of the Commission. In December, 1944 the Secretary of the Navy approved the use of funds in the amount of $6,000 to construct a new well, equipped with a turbine type pump. When installed, this pump was operated as necessary to meet the fluctuating load during the day and at such times as it was necessary to regulate the drawdown in the collecting well.

Other Problems

As can easily be imagined, the Navy, in its role of water supplier for all of the Keys, encountered many problems which were new to its officials. From the standpoint of its public relations, not the least of these stemmed from the desire of property owners to install direct taps to the aqueduct where it passed their property.

Under the terms of the Agreement between the Navy and the Florida Keys Aqueduct Commission, the Commission was the Navy's only civilian customer and the water sold to it was for serving its civilian and other customers through its own distribution system. The Navy had no part in the design of plans and specifications for local distribution systems nor in the establishment of the Commission's rate structure. Further, in the interest of protecting the aqueduct structure, the Navy felt justified in limiting the distances between points of connection to the main aqueduct. This was set at approximately 5000 ft. Exceptions were made to this rule where the Commission had a number of customers at a centralized location, or a reasonably large demand for water which would have made a long extension of large sized pipe necessary. It can be understood why such a limitation had to be placed upon the distance between connections. Most property owners along the Keys are located side by side. Certainly, all would feel justified in demanding a direct connection to the aqueduct passing their front yeard. Indeed, many reported that they had been told, prior to purchase of their property that direct connections to the Navy water line could be arranged. Many property owners felt that they were being very unjustly treated and an avalanche of letters to Senators, Congressmen, and even to the President,

resulted; the objective being to force the Navy to approve such "front yard" connections.

There were others among the property owners who attempted to take the matter into their own hands. Thefts of water through illegal connections were not unusual. Figure 15 shows one such illegal connection. It will be noted in Fig. 15 that the Commission had made a connection to the aqueduct at a blow-off point. This was a legal practice in every respect wherever the approval of the Navy had been obtained prior to the tap-in. The connection was originally so arranged that the water would pass first through a pressure-reducing valve; then a gate valve; and finally through a meter which measured the amount of water for which the Commission would be billed. A division of service in two directions was made immediately beyond the meter. This was common practice and permitted the Commission to serve two or more customers through a single meter. The picture shows where an unauthorized connection was made by a user, presumably without permission of anyone involved, particularly the Navy. This connection was probably made at an hour when legitimate users would not be aware of the water being turned off. The gate valve on the aqueduct side of the meter was then closed; a section of pipe was removed (probably by hack-saw methods) and one end of the section was threaded for a tee-fitting. The section was then assembled, inserted in the proper position and welded in place; not too big an operation, provided all materials and equipment were collected at the site beforehand. This illegal connection, and dozens of others, were found and reported. The aqueduct operating personnel keep a close watch to insure that such offenses are not repeated.

Further Corrosion Studies

Some of the steps taken to repair corrosion damage and to prevent further damaging inroads from that source have been described earlier. Such measures were taken for the prime purpose of maintaining water delivery service without interruption. It has been told how, because of the severely corrosive environment, corrosion troubles were experienced not long after completion of the installation. Over the years several of the underwater crossings were eliminated and alterations were made on the other sections of the line. By 1949, increasing water losses between Homestead and Key West, coupled with an increasing demand for water all along the line as well as at Key West, focused attention on the growing corrosion problem. Preliminary analysis by the Navy showed that it would be of great benefit to the government if the leakage could be better controlled and the critical areas of the pipe line deteriorating could be established. As a result of these analyses and after an experimental leakage survey had been made, a contract was let to The Hinchman Corporation of Detroit, Michigan, a firm specializing in corrosion engineering and surveys of underground structures, for a leakage survey on selected portions of the line. The portions of the line selected were those thought to be in the most critical condition by the operating personnel of the water line.

It may be well to describe the operations required in order to perform the leakage survey in view of conditions encountered on the Keys. Electronic leak detectors were used for detection of the leaks and it was quickly found that in order to make accurate readings, contact with the pipe was required at all locations along the line except where the pipe line ran under pavement. This condition is a result of the typical coral formation on the Keys. It was

also found necessary to locate accurately the position of the pipe so that contact to it could be easily made. The pipe in general has 3 to 4 feet of cover except at a few of the bridge approaches where the cover ranges up to 12 or 15 feet. On the bridge structures proper, the pipe is supported on brackets from the structures themselves. These structures vary in design, - see Figs. 16, 17 and 18.

The general location of the pipe line was well known to the operating personnel but in many areas the exact location was not known because of topographical changes since the line was constructed resulting from relocation of the roads and the large amount of construction taking place all along the Florida Keys. Consequently, it was necessary to stake the line out using electronic locators which accurately determine the exact position and depth of the line in the soil.

Subsequently, metal probes were driven to the pipe, to mount the leak detector pickup microphone at approximately 50 foot intervals. Leak detection readings were then taken at each interval and curves were plotted which indicated the noise level at the piping. These curves showed sharp peaks whenever a leak was detected and allowed the leaks to be located more accurately. Some 40 odd leaks were determined during the course of the entire survey which was ultimately extended to cover the entire line. These leaks were repaired and the line retested during the survey. It is, of course, difficult to estimate the amount of water lost by leakage from pressure piping. However, it is believed that between 450,000 and 600,000 gallons per day were being lost when the survey was made. With the exception of a few leaking Dresser couplings, blow-offs, air relief valves and construction tap-ins used for unmetered connections, all of the water loss was found to be a result of corrosion of the pipe. This corrosion was from the outside of the pipe and was found to occur where the coating had been damaged by roots, backfill or permeated with moisture.

A great many of the leaks were found to exist in groups as a result of very severe local environmental conditions which caused more than ordinary corrosion damage. However the survey reports also showed that the leaks were scattered pretty much along the whole length of the line and that the coating of the line in no place should be considered as a complete corrosion protection. It was concluded that unless corrosion mitigation measures were undertaken without delay, the incidence of leakage would increase rapidly and would result in the necessity for replacement of whole sections of the line within a few years. The leakage survey was therefore broadened to include a corrosion survey for the purpose of preventing future deterioration of the line.

The corrosion survey showed that the originally installed cathodic protection system required rehabilitation and that additional cathodic protection should be installed on the line in order that the sections not originally covered could be protected. It was found that the ground bed design on the initial cathodic protection installation should be redesigned and that new locations should be selected for other installations. In general rectifier installations were specified whenever power was available. One 50-ampere rectifier was found adequate for about ten miles of pipe line. Along a portion of the line electric power was not available and magnesium anodes were used for the cathodic protection. An insulating type of Dresser coupling was used in the original construction of the line and as a result of this, it was necessary to excavate to each coupling and to bond over the couplings so that the line would be electrically conducting. Fortunately a good portion of the line had been bonded when the initial cathodic protection was installed so that the

bonding did not mean an excavation to each coupling along the entire 135 miles of line.

The total cost of the cathodic protection, including bonding, was about $2,000 per mile. The cost of replacing the badly corroded pipe line had been estimated at $20,000 per mile. Since one section, comprising over 8 miles of pipe would immediately have had to be replaced if cathodic protection had not been applied, it is readily seen that considerable saving was effected in this instance alone by adoption of the corrosion control program. The over-all savings resulting from the operation of the entire control program amounted to a great deal more.

Default by Commission

Because of default by the Florida Keys Aqueduct Commission, early during the World War II, in the payments to Navy of their share of the costs of maintenance and operation of the aqueduct, and also on principal payments on their bonds held by the Reconstruction Finance Corporation it became necessary for the Congress to take action.

After thorough investigation the Congress, by the enactment of Public Law 379, 81st Congress, approved 25 October 1949, authorized the Secretary of the Navy to cancel the Agreement of 18 March 1941, with the Commission, and to enter into a new Agreement whereby the interests of the Government would be more adequately protected. When these steps had been taken, to the satisfaction of the Navy, the Commission, and the Reconstruction Finance Corporation, the Navy then proceeded to secure funds to pay back to the Commission such moneys as it had originally contributed to the cost of the Aqueduct. The Congress provided $1,096,392.91 for this purpose in the Second Supplemental Appropriations Bill, 1952. In due time all steps leading to full control of the Aqueduct by the Navy were completed. The new operating agreement now provides for the purchase of water by the Commission for resale to its customers to the extent that such water is surplus to the needs of the Navy. This Agreement places the Commission on a "pay as you go" basis, on a rate structure which has been carefully worked out to properly reflect actual water production costs. Such rates are subject to renegotiation periodically to allow adjustment to possible changed conditions of operation.

In order that the existing aqueduct installation can be made to serve both the growing Navy and civilian needs as long as possible, the Navy is particularly concerned in the elimination of waste in water usage. It matters not whether such waste occurs through misuse of water, or through leakage in the Commission's distribution system. The present rate structure is unusual in that it provides for increased cost of water as the demand increases. This added cost is passed on to the consumer, who in the interests of his own purse, cannot help but work in the direction of water conservation. The Navy considers this arrangement to be justified in all respects under the circumstances. The effectiveness of such device certainly could not be questioned in the normal American community; whether it will work in Key West and on the Upper Keys remains to be seen.

Growth of Civilian Water Demand on Upper Keys

Because of its particular importance in the over-all water supply picture as it affects the entire area, it is interesting to take note of the tremendous real estate development, commercial and residential, now occurring on the

Upper Keys. A yardstick by which this development may be gauged lies in the constantly increasing water demand of the Upper Keys. Such increase has been in operation since the day when the Florida Keys Aqueduct Commission first commenced to sell water to civilian consumers.

The phenomenal growth in civilian demand is indicated in Fig. 19, which illustrates the water consumption of the Upper Keys between the years of 1945 and 1952.

During the first two years of operation of the Aqueduct consumption on the Upper Keys was of little consequence. Figure 19 does not show the usage over this period. However, the water demand showed signs of rapid increase from the very beginning of service.

A brief study of the consumption curve shown in Fig. 19 indicates that the increase in consumption from 1945 to 1949 was phenomenal, but that it proceeded at a somewhat regular rate, approximating a straight-line course. In 1950, however, a marked increase in demand is shown. The consumption curve starts upward at a rapid rate, and it did not stop there. The curve shows that during the calendar years of 1950, 1951 and 1952, the Upper Keys actually used 128%, 166% and 230%, respectively, of the amount used during the calendar year 1949.

The curve, of course, does not show the great variation in water use which occurs between the months of any one year. Supporting data does show that many sudden increases in water use, far above normal, actually occurred during each of the years shown. For example, the records show that in July, 1952, the consumption on the Upper Keys amounted to 10,604,760 gallons. This amount was only 200,000 gallons more than the amount used in the previous month. Yet in August, 1952, the use had jumped to 17,308,892 gallons, and increased further in September, 1952 to 18,149,864 gallons. It then dropped to 9,885,241 gallons in October of the same year. This fluctuation in monthly demand can readily be explained by the fact that construction activity on the Upper Keys showed a marked upward surge during these months. Many such upward construction surges can only portend increased commercial and residential development on the Upper Keys. This means increased populations and water usage at points where the aqueduct can least afford to serve such demands. It must be remembered that the primary planned function of the aqueduct was, and always has been, to deliver water to Key West and not to help promote a rapidly growing real estate development of the Upper Keys.

Future Water Supply Picture

The Navy considers that it was not the intent of the Congress to make it responsible for supplying the water requirements of the civilian population of the Florida Keys for all time. Had it been so, it would have been tantamount to putting the Navy in the water business forever.

Navy policy leads in a far different direction than that. It is believed that the development of the area has not progressed to the point where private enterprise can begin to consider ways and means of meeting the future water requirements of the Keys with some promise of not being forced to the wall. Pending such time as this might become possible of accomplishment, the Navy plans to exploit to full advantage the production capacity of the present aqueduct system, without resorting to any expensive duplication of pipe lines, pumping facilities and other components of the system.

To the above end, some time ago the Navy engaged the engineering services of the firm Reynolds, Smith and Hills, Architects and Engineers,

Jacksonville, Florida, to conduct a study of the operation and hydraulic characteristics of the present plant and to determine the extent of final improvements to the system which might be made within limited funds available. The actual work which stemmed from the recommendations of the engineers includes, among other things, the installation of an additional diesel-driven booster pump at Marathon, Florida; a new booster pumping station at Tavernier, Florida; and additional softening, filtering and well and pump capacity at the treatment plant at Florida City.

The effect of these latest and final Navy improvements will be to increase the production capacity of the system from about 3.2 million gallons per day to approximately 4.7 million gallons per day, sufficient to meet the reasonable water needs of the area for only a few years ahead.

The Navy, unless charged otherwise by the Congress, intends to limit its program of expansion of the aqueduct system to that which will have been accomplished when the above-mentioned work has been completed. When civilian growth reaches the point where its water requirements exceed that which is surplus to Navy's needs, further development can only proceed at the expense of existing civilian consumers. The solution of the future water supply needs of the entire area beckons to private enterprise to go to work.

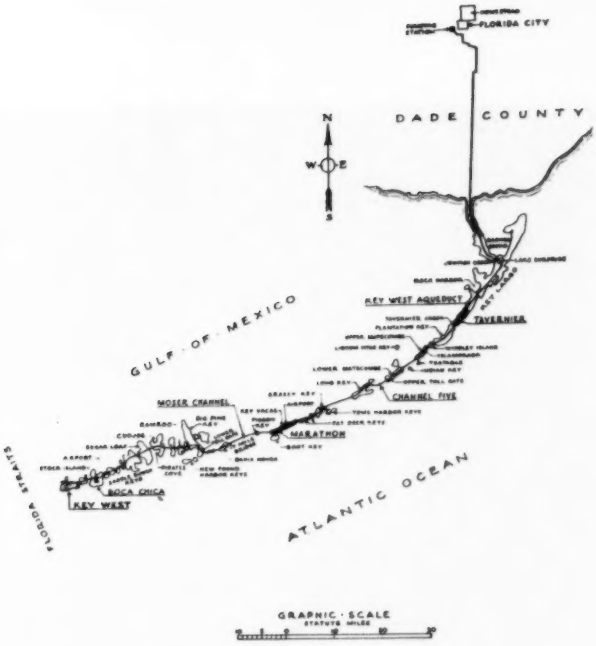

Fig. 1.--Location Plan of Key West Aqueduct.

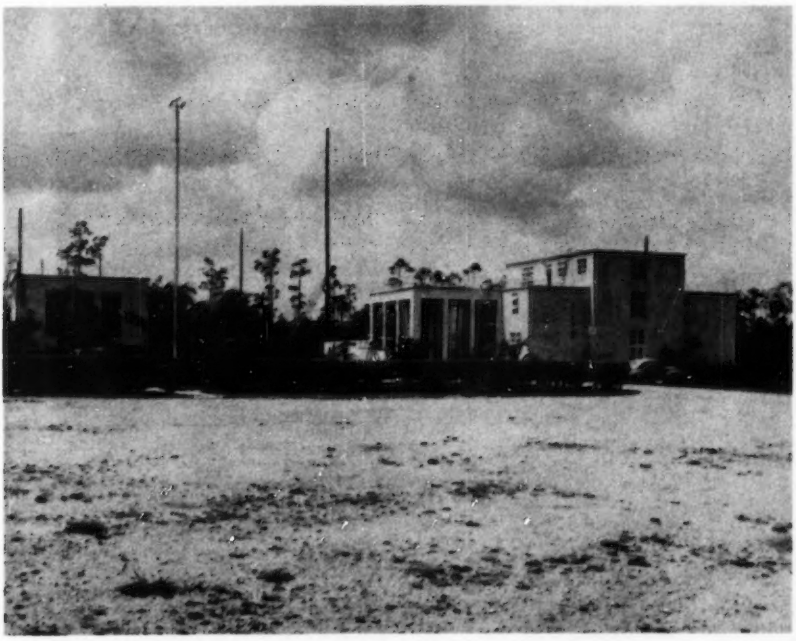

Fig. 2.--Florida City Facilities. - Original Pumping Plant shown at left was constructed in 1942; Softening Plant, constructed in 1945; appears at right.

Fig. 3.--Mainland South of Homestead, Florida. - Excavation for Pipe-line, using Back Hoe.

Fig. 4.--Jewfish Creek Underwater Crossing. - View, looking north shows pipe partially submerged by filling with water.

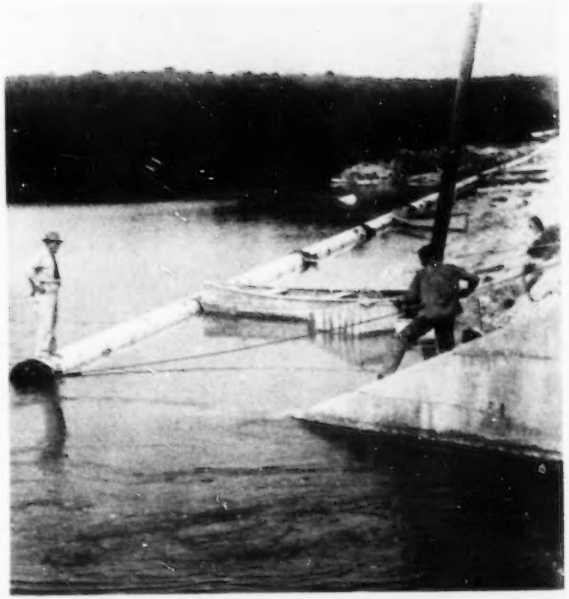

Fig. 5.--Tavernier Creek Underwater Crossing - Pipe ready to float into place and be sunk to bottom of creek-bed.

Fig. 6.--Tea Table Channel Bridge - Two (2) temporary by-pass lines on East side of Bridge.

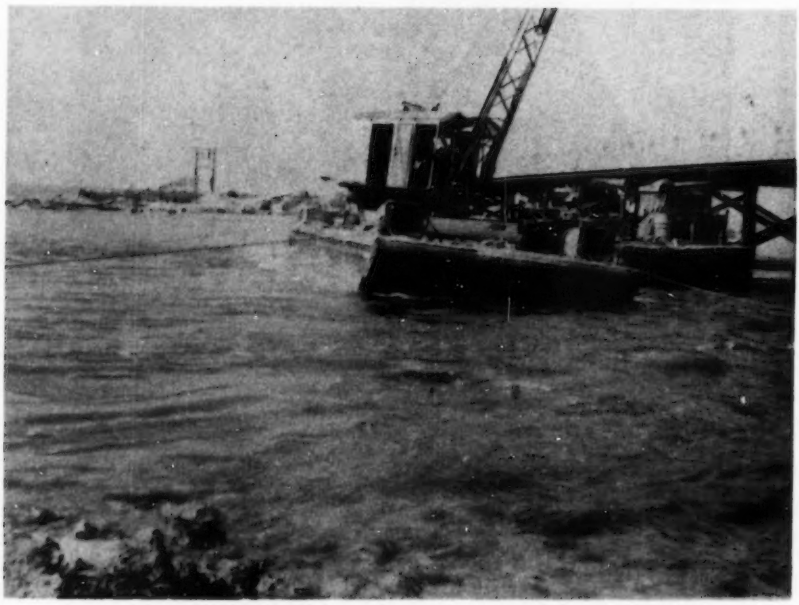

Fig. 7.--Tea Table Channel - (Looking South.) Wash at Barge illustrates swift current through Channel.

Fig. 8.--Tea Table Channel - Corrosion of Dresser coupling bolts where enamel had been knocked off. Crater-shaped pits equal to 1/2 diameter of 5/8-inch bolts.

Fig. 9.--Tea Table Channel - Harness Set Bolt. 1/8-inch diameter. Finger points to severe corrosion where bolt passed through hole in lug. Reduction in diameter, approximately 1/8-inch.

Fig. 10.--Tea Table Channel - Illustrates gouge in enamel from construction equipment.

Fig. 11.--Tea Table Channel - Largest hole found about 1/2-inch x 3/8-inch. Enamel appeared to have suffered slight abrasion.

Fig. 12.--Tea Table Channel - Two (2) crater shaped holes resulting from abrasion of enamel.

Fig. 13.--Tea Table Channel - Same holes as shown in Fig. 12 after enamel had been chipped away. Another pipe length is shown in lower background.

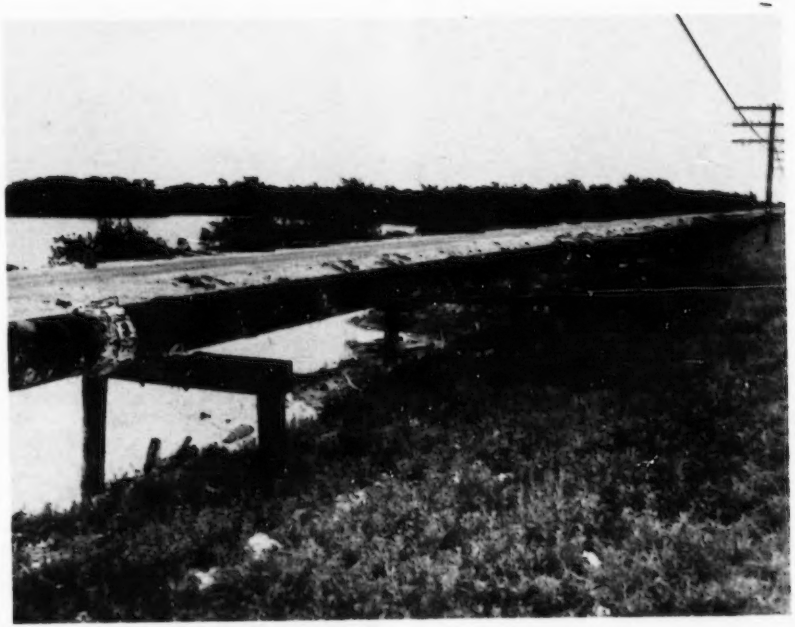

Fig. 14.--Aqueduct Supported on Pile Bents. - Section above Jewfish Channel.

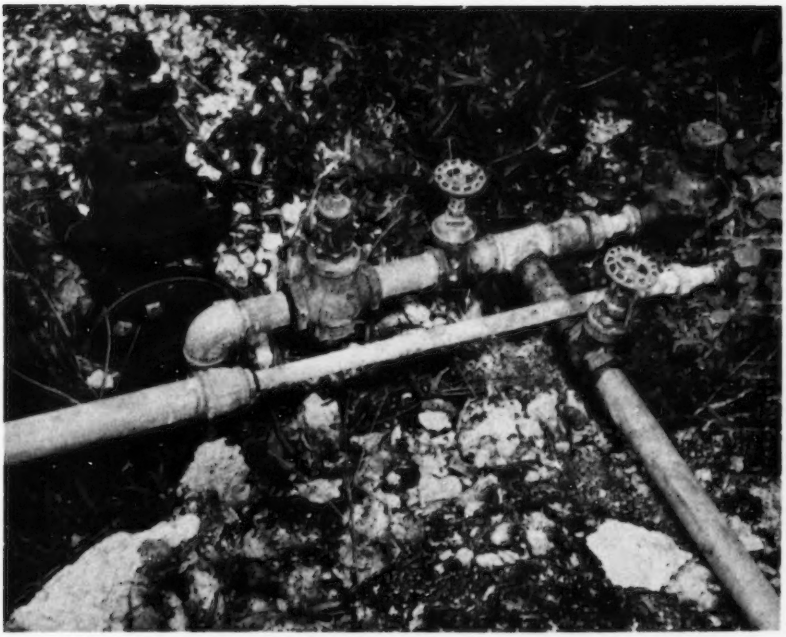

Fig. 15.--Water Being Stolen Through an Illegal Connection.

Fig. 16.--Aqueduct Suspension on Saddle Bunch Viaduct 3. Note concrete arch construction. Vacuum-relief valve is shown.

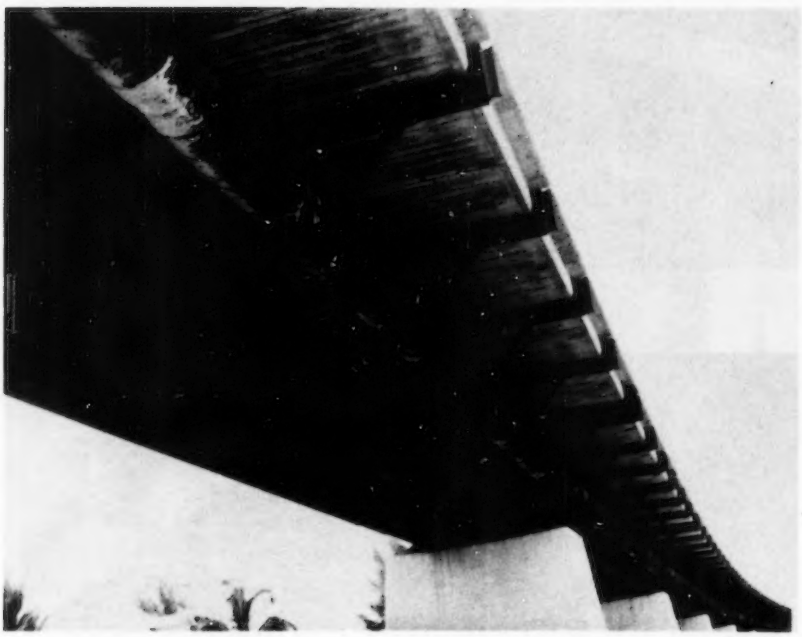

Fig. 17.--View from Pigeon Key Shows Aqueduct Suspension on Seven Mile Bridge. Note plate girder construction.

Fig. 18.--Close-up View from Pigeon Key Shows Detail of Bracket Supporting Aqueduct from Steel Plate Girder.

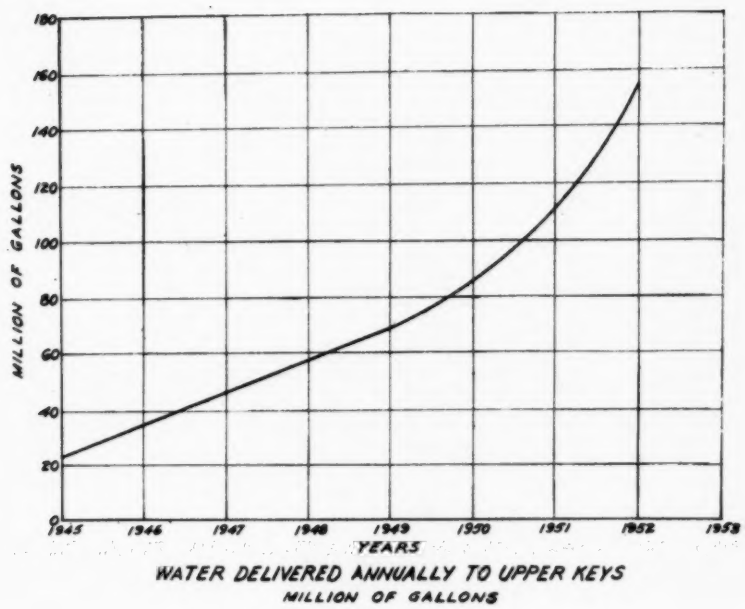
180
160
140
120
100
80
60
40
20
0
MILLION OF GALLONS
1945
1946
1947
1948
1949
1950
1951
1952
1953
YEARS
WATER DELIVERED ANNUALLY TO UPPER KEYS
MILLION OF GALLONS

Fig. 19